HUMAN EXPOSURE ROUTES TO SELECTED PERSISTENT TOXIC CHEMICALS IN THE GREAT LAKES BASIN: A CASE STUDY

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Running Title: Exposure Routes to Chemicals in the Great Lakes

Abstract: The main routes of human exposure to persistent toxic chemicals are air, drinking water and food. Occupational exposure can also be significant. It is important to know the relative contributions of these routes to the total body burden so that programs to reduce human exposure can focus on the most significant exposure pathway(s). This paper assesses the relative importance of the three main non-occupational human exposure pathways to selected persistent toxic chemicals in the Great Lakes basin, using Toronto and Southern Ontario as a case study. This has been done by reviewing data on ambient concentrations in air, drinking water and food, and calculating the estimated human exposure from each route. For the chemicals studied food was the most significant route of exposure, although concentrations were no greater than in food grown in the U.S. All detected concentrations were below the Maximum Residue Limits (MRLs) established in the Canadian Food and Drugs Act.

INTRODUCTION

The Great Lakes basin presents a unique challenge for studying human exposure to persistent toxic chemicals, not only because many chemicals are extensively used, manufactured and disposed of in the region, but also because there are approximately 37 million residents.

Concentrations of persistent toxic chemicals in environmental media have been monitored for many years by most state, provincial and federal environmental agencies in the Great Lakes basin. They have shown that concentrations of some persistent toxic chemicals declined from the mid-1970's to approximately 1980. Subsequently, however, concentrations have remained approximately the same, and in some cases they have even increased slightly. Several studies have reported the concentrations and effects of persistent toxic chemicals in selected species in the Great Lakes ecosystem. These studies include research on the concentrations of organochlorine pesticides and other chemicals in herring-gull eggs (1), the prevalence and causes of cancerous tumours in fish (2) and the health effects associated with feeding experimental rats and mink diets containing Great Lakes fish (3,4,5,6).

Research has also been undertaken on human tissues. One study conducted in 1984 demonstrated the presence of several persistent toxic organic chemicals in human adipose tissue taken from autopsy samples of residents of Kingston and Ottawa, Ontario (7). There were no significant differences in mean concentrations between the

two groups, although the Kingston means were slightly higher than the Ottawa means. The reported concentrations were similar to those detected in studies of other Canadian (8), U.K. (9) and U.S. (10) residents. Polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) have also been detected in Canadian human adipose tissue (11).

The research discussed above demonstrates that there is human exposure to persistent toxic chemicals in the Great Lakes basin, although in many cases the routes of human exposure have not been well characterized. Furthermore, the relative importance of the different exposure pathways has not yet been established for specific chemicals.

This paper is intended to provide an overall assessment of the three major non-occupational exposure pathways; air, drinking water and food, and to examine their relative importance. This was done using ambient concentrations of persistent toxic chemicals in air, drinking water and food, and calculating the approximate human exposure from each by assuming average amounts of air inhaled, drinking water ingested and food consumed. The ambient concentrations used were taken from the literature, but because of the lack of current data on chemical concentrations in fresh food (in particular fruits and vegetables) grown in the Great Lakes basin, a limited amount of chemical analysis was undertaken. Estimated doses were not calculated. The relative

significance of the different exposure pathways was deduced from the calculated exposure estimates.

This paper focusses on human exposure to selected persistent and toxic chemicals in the Toronto and Southern Ontario region of the Great Lakes basin. This is because there is a considerable amount of information available on this region. This study should be regarded as a pilot study only, and any conclusions drawn may not necessarily be valid for other regions within the Great Lakes basin.

HUMAN EXPOSURE TO PERSISTENT TOXIC CHEMICALS IN AIR

Most air monitoring in the Great Lakes basin has been conducted in relation to specific emissions, such as industrial point source discharges, so there are few data available on ambient atmospheric concentrations of persistent toxic chemicals.

Ambient atmospheric concentrations of persistent toxic chemicals have not been comprehensively determined in Toronto or Southern Ontario. However, ambient atmospheric concentrations of organic chemicals in the Great Lakes have been determined (12). These are shown in Table 1. The estimated human exposures were calculated by assuming a tidal volume of half a litre and a frequency of 15 breaths a minute (13).

Table 1 to be inserted near here.

Ambient concentrations of polychlorinated PCDDs and PCDFs have not been determined in Ontario air.

There are some data available on ambient atmospheric concentrations of inorganics in specific regions of the Great Lakes basin. These, however, may not be applicable to Toronto or Southern Ontario.

Most data on ambient atmospheric concentrations are for outdoor air, although most people are outside for only very limited periods of time, depending on prevailing weather conditions. No major studies have been reported on concentrations of persistent toxic chemicals in indoor air in the Great Lakes basin and most of the published data from elsewhere report atmospheric concentrations of pesticides following treatments for pests, such as termites. Such treatments frequently give rise to detectable concentrations of pesticides, and although these concentrations cannot be construed as being ambient, several surveys have shown that the majority of urban residents use pesticides (for example, references 14 and 15). It is therefore difficult to estimate average human exposure to persistent toxic chemicals in indoor air in the Great Lakes basin.

HUMAN EXPOSURE TO PERSISTENT TOXIC CHEMICALS IN DRINKING WATER

Toronto's drinking water is the largest supply system on Lake Ontario and water samples are analysed 2-3 times a year by the Metropolitan Toronto Works Department for the presence of

approximately 170 chemicals, of which about 135 are organic and 35 are inorganic. Between 1978 and 1984, 51 chemicals were identified by the Metropolitan Toronto Works Department, although most were detected infrequently and at concentrations well below the provincial drinking water objectives. A recent study estimated the average concentrations of chemicals detected between 1978 and 1984 (16). These average concentrations were calculated using data on treated drinking water from all four filtration plants. Concentrations below the minimum detection level were taken as being zero for averaging purposes. Assuming an average consumption of two litres a day (17) human exposure estimates were calculated from these average concentrations. The average concentrations and the estimated human exposures are shown in Table 2.

Table 2 to be inserted near here.

As well as being ingested, drinking water is also used for many other purposes that could result in human exposure to persistent toxic chemicals. The most obvious of these are bathing and showering. Recent evidence suggests that many organic chemicals can be absorbed through skin (18,19), although the relevance of this route of exposure has not been fully assessed. The extent of absorption depends on the type of pesticide, its concentration, the solvent and on the site and duration of dermal exposure. One study of volatile organics estimated that dermal absorption contributed between 29 and 91% of the total dose from drinking

water (20). It is therefore likely that dermal exposure to persistent and toxic chemicals in drinking water contributes to overall human exposure. Inhalation during showering or bathing may also be a significant exposure pathway.

HUMAN EXPOSURE TO PERSISTENT TOXIC CHEMICALS IN FOOD

Foods from the Great Lakes basin have been analysed individually and in composites for the presence of persistent toxic chemicals, although total human exposure from fresh food grown in the Great Lakes basin has never been estimated.

To estimate the average human exposure to persistent toxic chemicals in fresh food grown in the Great Lakes basin and available in Toronto, the existence of an 'average' diet was postulated, because there is no published information available on 'representative' diets. The only available data are food purchase data for Ontario residents (21). These were used to estimate the average ingestion of selected persistent toxic chemicals. The use of food purchase data to infer a 'representative' diet is likely to overestimate human ingestion because of the amount of food purchased and not consumed.

Although it was necessary to postulate the existence of a 'representative' diet for Toronto's residents, dietary habits are likely to be diverse. This is partly because of the ethnic diversity in Toronto. Eating habits also vary with age, occupation, social status, personal preferences, religion, etc.

These factors can be used to define population sub-groups that may consume significantly larger amounts of persistent toxic chemicals such as sport fishermen and their families and nursing infants.

Fish

Samples of fish from the Great Lakes have been chemically analysed for many years. Since 1978, the Ontario Ministry of the Environment (OMOE) has published an annual guide containing recommendations on the consumption of sportfish from Ontario lakes, including Lake Ontario (22).

A report published by the U.S. Fish and Wildlife Service contains data from fish collected from locations in the Great Lakes in 1980 - 1981 (23). Nearly all samples contained detectable residues of DDT and its metabolities, PCBs, dieldrin, chlordane and toxaphene. Residues of endrin and heptachlor were detected more frequently in Lake Michigan fish than in fish from the other Great Lakes. Some samples also contained HCH isomers, HCB and methoxychlor.

Concentrations of many persistent toxic chemicals in fish in Lake Ontario have decreased since the mid-1970s, although concentrations of some chemicals only decreased until 1980 or 1981, and have remained constant or even increased slightly since then. For example, in 1977 the mean concentration of PCBs in lake trout (whole fish, age 4+) was 8.00 mg/kg (24). This decreased to 3.67 mg/kg in 1983. A similar pattern can be seen in concentrations of mirex and DDT, although an increase in DDT

concentrations occured in 1983. Further data are needed to confirm these trends.

1980 data from the OMOE for fish in Toronto Harbour contain results for the edible portion of fish only. These are shown in Table 3 (25). The estimated human exposures were calculated from food purchase data for Ontario residents, published by Statistics Canada (21), using an estimated average annual consumption of freshwater fish of 0.53 kg/y.

The estimated human exposures shown in Table 3 are likely to overestimate actual exposure because most commercially available fish are likely to contain lower concentrations of these persistent toxic chemicals.

Table 3 to be inserted near here.

Great Lakes fish have recently been analysed for the presence of PCDDs. Fish from Lake Ontario were analysed for 22 T4CDD isomers and compared with fish from Lake Erie and the Eastern Pacific Ocean (26). Only 2,3,7.8-TCDD was found in the Lake Ontario fish, and fish from the two control locations did not contain detectable concentrations.

The OMOE has also analysed fish samples from the Canadian Great Lakes for the presence of PCDDs (27). Except for trace amounts of 2,3,7,8-TCDD in lake trout from Peninsula Harbour, the fish of Lakes Superior, Huron and Erie did not contain detectable

residues. In contrast, until recently 2,3,7,8,-TCDD was often detected in fish samples from the Niagara River and Lake Ontario. Data suggest that 2,3,7,8-TCDD levels are highest in young-of-the-year (less than one year old) spottail shiners collected from a creek that receives drainage from the Love Canal area, and in lake trout from the western end of Lake Ontario. The human consumption of lake trout longer than 45 cm (18 inches) from western Lake Ontario was restricted because concentrations of T4CDD are likely to exceed 20 ppt (27). Recent data reviewed by the OMOE indicate that some fish which do not contain 2,3,7,8-TCDD may contain other T4 and P5 CDDs and CDFs, as well as 2,3,7,8-TCDF. 2,3,7,8,-TCDF has been detected at concentrations between 8 - 15 pg/g. Higher chlorinated congeners are not usually detected. Consequently, freshwater fish are apparently not a source of higher chlorinated PCDDs and PCDFs to humans.

It is difficult to estimate human exposure to PCDDs and PCDFs from Lake Ontario fish because of the limited amount of data available on concentrations in fish. Table 4 shows a summary of the 1980-81 OMOE available data on 2,3,7,8-T4CDD in Lake Ontario fish (27).

Table 4 to be inserted near here.

Assuming an estimated average freshwater fish consumption of 0.53 kg/y (calculated from Statistics Canada food purchase data (21)), the estimated human exposure can be calculated to be between 0 - 14.52 ng/y of 2,3,7,8,-TCDD.

Dairy Products

Most of the research on persistent toxic chemicals in dairy products from Ontario has reported residue levels in cows' milk (28,29,30,31). The most recent published report examines data for 1983 (30). The average concentrations of organochlorines are shown in Table 5. The estimated human exposures were calculated using an estimated average consumption of 23.62 litres/y of whole milk. This was calculated using Statistics Canada food purchase data (21).

Table 5 to be inserted near here.

Recent unpublished data from Frank et al. shows the results of PCB analyses of Ontario cows' milk samples collected in 1985 (31). The average PCB concentration was 0.014 mg/kg butterfat. This corresponds to an average whole milk concentration of 0.0005 mg/kg, assuming 3.8% butterfat. If an estimated average consumption of 23.62 litres/y of whole milk is also assumed (calculated from Statistics Canada food purchase data (21)), the estimated human exposure can be calculated to be 0.018 mg/y. This is slightly less than the estimated human exposure from 1983 milk samples shown in Table 5.

Previous papers published by Frank et al. include data on cows' milk samples collected between 1967 - 1969 (28) and in 1977 (29). If the data from all three papers are compared, the average concentrations of organochlorines can be seen to have decreased

over time. Concentrations of total DDT decreased by approximately an order of magnitude, although concentrations of gamma HCH were only slightly less in 1983 than they were in 1967 - 69. These decreases reflect the decreased use of organochlorine pesticides in Ontario.

Human Milk

It has been known for many years that human milk can contain persistent toxic chemicals, in some cases at higher concentrations than those detected in cows' milk. This has caused some concern among health professionals and the public. In Canada, this problem has been highlighted by a recent report showing a large increase in national breast-feeding trends from 38% of mothers in 1963 to 75% in 1982 (32). There has also been an increase in the number of months of breast-feeding.

Concentrations of PCBs and organochlorine pesticides have been determined in Canadian human milk samples (33). The results are summarized in Table 6. Estimated exposures were calculated by assuming an average ingestion of 600 ml of human milk a day (34).

Table 6 to be inserted near here.

These results show that many organochlorine residues have been detected in Canadian human milk samples. However, this study was conducted in 1975, so the concentrations may not represent present concentrations accurately.

Concentration PCBs in samples of human milk have been estimated for Ontario residents (35). Data for 1971 - 1985 are shown in Table 7. The estimated exposures were calculated as described above.

Table 7 to be inserted near here

The mean concentrations of PCBs in human milk samples from Ontario residents have generally decreased between 1971 - 72 and 1985, although in 1983 the mean PCB concentration was the highest detected. The 1985 estimated exposure can be used to calculate an average total exposure to PCBs of 1.08 mg for 3 months breast-feeding and 2.16 mg for 6 months breast-feeding. The exposure estimates for Ontario residents are lower than those estimated from the Canadian survey conducted in 1975 (see Table 6).

Meat and Eggs

Ambient concentrations of persistent toxic chemicals have been determined in meat, poultry and egg samples from the Great Lakes basin. Residues of organochlorine pesticides have been detected in fat from beef and pork carcasses marketed in Ontario between 1969 and 1981 (36). The results showed that mean concentrations of total DDT decreased from 257 ug/kg in 1971 - 72 to 12 ug/kg in 1981 in samples of beef fat, and from 356 ug/kg in 1971 - 72 to 5 ug/kg in 1981 in samples of pork fat. Similar decreases were observed for PCBs. Dieldrin concentrations decreased by an order of magnitude over the same time period. Chlordane and heptachlor

epoxide were rarely detected in beef or pork fat; however, the incidence in beef fat increased in 1973. Chlordane was detected at low concentrations (1-2 ug/kg) in beef fat in the mid-1970's, and remained detectable through 1981. Lindane residues in both beef and pork fat fluctuated from year to year and appeared to vary with the amount of lindane used to control insect pests. A summary of the most recent (1981) data is shown in Table 8. Estimates of human exposure were calculated using food purchase data from Statistics Canada (21). The estimated average consumption of beef was calculated to be 16.81 kg/y, the estimated average consumption of pork was calculated to be 7.55 kg/y. Fat contents of 20% for beef and 30% for pork were assumed.

Table 8 to be inserted near here

Organochlorine residues have been investigated in chicken and egg fat (37). This study reported concentrations between 1969 - 1982 in samples from Ontario. During this time total DDT and PCB residues decreased significantly. Dieldrin concentrations decreased less markedly. Chlordane and heptachlor epoxide were rarely detected (minimum detection level = 1 ug/kg); however, the incidence in chicken fat increased after 1973. This was probably a result of the removal of aldrin, dieldrin and heptachlor in 1969 for soil insect control, and the subsequent increased use of chlordane until 1977. Lindane residues were infrequently detected. A summary of the most recent data (1981 - 82) is shown in Table 9. Estimated human exposures were calculated by assuming

the average fat content of chicken meat and eggs to be 17%, the average weight of an egg to be 75g and the estimated average consumption of chicken and eggs to be 15.81 kg/y and 13.50 kg/y, respectively. The estimated average consumption of chicken and eggs was calculated from the Statistics Canada food purchase data (21).

Table 9 to be inserted near here

Fruit and Vegetables

Most of the published research on organochlorine pesticide residues in fruit and vegetables grown in Ontario has been reported by Frank's research group (38,39,40). This includes a determination of residues in onions and carrots grown on organic soils in Ontario between 1975 and 1980 (38), and a study of the disappearance of nine pesticides on celery and lettuce grown in Ontario between 1977 and 1980 (39). None of the pesticides in the first study have been mentioned in this report, and endosulfan was the only relevant pesticide in the second study. In this investigation, an average concentration of 1.2 mg/kg (range = 0.09 - 2.1 mg/kg) was detected in the 1978 samples.

There are also unpublished data available describing the pesticide residues in Ontario vegetables for 1980 - 84 (40). Residues of organochlorine pesticides were detected infrequently.

Food composites

To supplement the food data described above, composites of fresh foods grown in Southern Ontario and purchased in Toronto supermarkets were analysed. Five food composites were made up from fresh food grown in Southern Ontario and purchased in Toronto supermarkets. These were:

a) Fresh meat and eggs

b) Root vegetables (including potatoes)

c) Fresh fruit

d) Leafy and other above ground vegetables

e) Cows' milk

The relative proportions of different food items in each composite was based on calculated relative proportions derived from food purchase data for Ontario residents (21). These are shown in Table 10.

Table 10 to be inserted near here

Some types of foods were included in the estimates of food consumption for Ontario residents, but Ontario varieties were not available in any of the stores at the time of purchase. These items were excluded, and the percentage composition of the composite sample was re-calculated.

A randomly chosen 100g sample of the edible portion of each food item was finely chopped and after mixing the composites were made up to a final weight of 100g each, using the relative proportions shown in Table 10 above.

The cows' milk composite was made up by mixing four one litre cartons of 2% milk from different dairies and taking a composite sample of 100 ml for analysis.

The data in Table 11 show that a wide variety of organochlorine residues were detected in all of the composite samples, although all concentrations were below the Maximum Residue Limits (MRLs) established in the Canadian Food and Drugs Act. The presence of these residues in composite food samples is not unexpected because they are all lipophilic pesticides (except for PCBs) that have been used on agricultural land and crops, and they are all environmentally persistent. Some concentrations were relatively close to the minimum detection levels. The standard error on such concentrations is likely to be relatively large, so they should be interpreted cautiously.

Table 11 to be inserted near here.

Chlorobenzenes were detected in all composites, although the root vegetable composite contained only 1,3-dichlorobenzene and hexachlorobenzene. Trichlorobenzenes were identified in all other composites. Hexachlorobenzene was detected in all composites except fruit.

Gamma HCH (lindane) was detected in all composites except cows' milk. Alpha HCH was found in the fruit, milk and eggs and meat composites. In contrast, heptachlor was not detected in any of the composites, although heptachlor epoxide was found in the cows' milk and the eggs and meat composites.

Aldrin was not detected, although dieldrin was found in all five composites. The highest concentration of dieldrin was detected in root vegetables.

Chlordane and endosulfan isomers were detected in all five composites. Endrin was detected in all composites, except eggs and meat. DDT and its metabolites were found in all composites. Neither mirex nor its degradation product, photomirex, were detected in any of the composites. Methoxychlor was not detected in any of the composites, although it is registered for use in Ontario on selected vegetables. PCBs were detected in the fruit, milk and eggs and meat composites.

Unfortunately, freshwater fish were not available in any of the stores from which food was purchased, so they were excluded from the analysis. This could be important because of the relatively high concentrations of many persistent toxic chemicals in fish from the Great Lakes, although Great Lakes residents also consume fish from other regions and commercially grown fish.

It is difficult to compare these data with those discussed for different food types above. For example, the cows' milk data

shown in Table 5 are for whole milk, while those in Table 11 are for 2% butterfat. However, concentrations of persistent toxic chemicals in the eggs and meat composite are lower than those reported by Frank et al. for pork and beef fat and shown in Table 8.

The results shown in Table 11 can also be compared to 1980-1982 data from the U.S. Total Diet Study (41). This study averaged chemical concentrations detected in twenty-seven market basket samples collected from across the U.S. Generally, the detected concentrations in fresh food are similar to those shown in Table 11, although some concentrations are higher in U.S. foods, and others lower. Detected concentrations of A-HCH and heptachlor epoxide were slightly higher in the U.S. samples, but residues of DDT were higher in the Southern Ontario samples. This suggests that fresh food grown in Southern Ontario is no more and no less contaminated with these residues than foods grown in the U.S. Data from the Canadian Total Diet Study is less recent, and so have not been used for comparative purposes in this report.

Table 12 to be inserted near here.

The analysis for PCDDs and PCDFs shows that the composites contained detectable amounts of both groups of compounds. Some of the detected concentrations are relatively close to the minimum detection levels. The standard error on such concentrations is likely to be relatively large, so they should be interpreted

cautiously. The root vegetable composite contained mainly H7- and O8CDDs and H7- and O8CDFs. The cows' milk composite contained the lower chlorinated congeners T4CDF, T4CDD and P5CDF, and all of the H7- and O8- more heavily chlorinated congeners. The eggs and meat composite contained the same lower chlorinated congeners, except for T4CDD. The only heavily chlorinated congener it contained was O8CDD. H6CDF analysis was severely impaired by the presence of an interference, making detection of residues impossible below 5 ug/kg. Unfortunately, there are no comparative data published on concentrations of PCDDs or PCDFs in food grown in the Great Lakes basin, so it is difficult to estimate the significance of these results.

The approximate dietary intake of each chemical was calculated using the estimated annual consumption of the different food types in each composite (see Table 10). The relative exposures from each composite food group have also been calculated. These data are shown in Tables 13 and 14.

Table 13 to be inserted near here.

Table 14 to be inserted near here.

These estimated intakes may not represent annual exposures from fresh foods accurately, because the composites contained only fresh food grown in Southern Ontario. Fresh foods grown elsewhere are also available and consumed by Toronto residents. Therefore,

actual exposures will also depend on the relative proportions of Ontario grown fresh food and that grown elsewhere, as well as the concentrations of these persistent toxic chemicals. The estimated exposures may therefore not represent actual exposures from all fresh food consumed.

The relative exposures for each food composite for each chemical have also been calculated. They have been expressed as the percentage of total exposure for each chemical. Average percentages have also been calculated for organochlorines and for PCDDs/PCDFs.

These data show that most exposure to organochlorines (approximately 30%) would have come from the eggs and meat composite, and least (approximately 8%) from the fruit composite. Conversely, most exposure to PCDDs and PCDFs (approximately 69%) come from the fruit composite. The least exposure (0.5%) would have come from the leafy vegetable composite.

An exposure assessment for PCBs has been published by Bennett, in which total exposure from food and drinking water was estimated to be 8.6 mg/y (42). This is much more than the estimates shown in Table 13. Bennett's exposure values were obtained from a literature review, and most of the data cited are from the 1970s, and so may not represent current exposures.

EXPOSURE ASSESSMENT

Estimates of average human exposure to selected persistent toxic chemicals have been calculated for air, drinking water and food. These estimates are intended to describe average exposures in general terms, rather than to provide definitive assessments. This section integrates these estimates to estimate non-occupational exposure through the three pathways discussed above. It was not possible to include PCDDs or PCDFs in the exposure assessment because ambient data on these chemicals are largely unavailable for Toronto and the Southern Ontario region.

An exposure assessment for a 'representative' Ontario adult is shown in Table 15. The data used in this table have been discussed in this paper. The assessment shows that approximately 86% of non-occupational exposure to the selected persistent toxic chemicals is from food, approximately 10% drinking water, and 4.5% for air.

Table 15 to be inserted near here.

A second exposure assessment can also be prepared using just the data from the food composites discussed above, and the same drinking water and air data. This is shown in Table 16.

Table 16 to be inserted near here.

This assessment also shows that approximately 86% of total non-occupational exposure for these chemicals comes from food, approximately 11% from drinking water and 3.5% from air. These estimates are very similar to those in Table 15, and confirm the results shown in Table 11. The results in Table 16 also confirm that fresh food would be the major non-occupational route of human exposure to the selected persistent toxic chemicals in the Great Lakes basin that were studied in this paper.

These proportions could be used to establish research, monitoring and remediation priorities for these chemicals. In recent years, considerable attention has been focussed on human exposure to many of the chemicals studied in this paper in drinking water alone. This paper suggests that exposure through this pathway may only be a small proportion of total non-occupational exposure from these chemicals, although this could be modified by bioavailability. It may therefore be desirable to re-evaluate the current emphasis on the presence of these chemicals in drinking water and devote more resources to examining their presence in food.

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TABLE 1: 1981 Ambient Atmospheric Concentrations and Estimated Human Exposure to Organic Chemicals in the Great Lakes Basin

Chemical	Range[1] (ng/m³)	Mean[1]	Estimated Human Exposure[2] (ug/y)
Total PCBs	0.4-3.0	1.0	3.942
Total DDT	0.01-0.05	0.03	0.118
A-HCH	0.25-0.4	0.3	1.183
G-HCH	1.0-4.0	2.0	7.884
Dieldrin	0.01-0.1	0.05	0.197
HCB	0.1-0.3	0.2	0.788
Total PAH	10-30	20	78.840
Anthracene	0.1-1.0	0.6	2.365
Phenanthrene	0.1-1.0	0.6	2.365
Pyrene	0.1-4.0	1.1	4.336
Benzo-a-anthracene	0.1-1.0	0.5	1.971
Perylene	0.1-2.0	0.6	2.365
Benzo-a-pyrene	0.1-2.0	1.0	3.942
Dibutyl phth.	0.5-5.0	2.0	7.884
Diethylhexyl phth.	0.5-5.0	2.0	7.884

Note:
A = alpha
G = gamma
Phth. = phthalate
[1] = See reference 12
[2] = Calculated by the author assuming a tidal volume of half a litre and a frequency of 15 breaths a minute (see reference 13)

TABLE 2: Mean Concentrations and Estimated Human Exposure to Selected Persistent Toxic Chemicals Detected in Toronto's Drinking Water 1978-1984

Chemical	Average Concentration in Drinking Water[1] (ug/l)	Estimated Human Exposure[2] (mg/y)
Organics		
A-HCH	0.034	0.025
B-HCH	0.0005	0.0004
G-HCH	0.0004	0.0003
Aldrin	0.002	0.0014
Dieldrin	0.001	0.0007
DDE	0.0003	0.0002
Dibutyl phth.	2.547	1.859
Dioctyl phth.	0.133	0.097
Bis ethyl hexyl phth.	63.54	46.38
Diethyl phth.	0.0107	0.0078
Atrazine	0.03	0.022
Hexachlorobenzene	0.002	0.0015
Inorganics		
Arsenic	0.15	0.109
Boron	25.8	18.834
Cadmium	1.2	0.876
Chromium	1.8	1.314
Cyanide	0.81	0.591
Mercury	0.06	0.043
Selenium	0.16	0.116

Note:
A = alpha
B = beta
G = gamma
phth. = phthalate
[1] = See reference 16
[2] = Calculated by the author assuming an average consumption of two litres a day (see reference 17)

TABLE 3: Average 1980 Concentrations and Estimated Human Exposure to Persistent Toxic Chemicals in the Edible Portion of Fish from the Toronto Harbour

Chemical	Rainbow Trout		Northern Pike		White Sucker	
(mg/y)	Av. concentration[1] (mg/kg wet wgt.)	Estimated Human Exposure[2] (mg/y)	Av. concentration[1] (mg/kg wet wgt.)	Estimated Human Exposure[2] (mg/y)	Av. concentration[1] (mg/kg wet wgt.)	Estimated Human Exposure[2]
PCBs	0.395	0.209	0.636	0.337	0.280	0.148
Total DDT	0.099	0.052	0.173	0.092	0.02	0.011
Chlordane	0.048	0.025	0.061	0.032	0.018	0.009
HCB	0.004	0.002	0.003	0.002	0.003	0.002
Mirex	0.01	0.005	0.033	0.017	0.001	0.0005
Heptachlor	ND	-----	ND	-----	ND	-----
A and B-HCH	0.029	0.015	0.015	0.008	0.003	0.002
G-HCH	0.002	0.001	Trace	-----	ND	-----
Aldrin	ND	-----	ND	-----	ND	-----
Mercury	0.07	0.037	0.34	0.180	0.160	0.085
Cadmium	0.04	0.021	0.04	0.021	0.043	0.023
Lead	0.91	0.482	1.14	0.604	2.40	1.272
Arsenic	0.10	0.053	0.157	0.083	0.085	0.045
Selenium	0.27	0.143	0.245	0.130	0.237	0.125

Note:
A = alpha
B = beta
G = gamma
ND = Not detected
---- = Information not available
[1] = See reference 25
[2] = Calculated by the author, assuming an estimated average consumption of 0.53 kg/y (calculated from reference 21)

TABLE 4: 2,3,7,8-TCDD Concentrations in Lake Ontario Fish (27)

Location	Species	Concentration Range (pg/g)	Mean (pg/g)
Jorden Harbour	Brown Trout	ND - 19.0	-
	White Bass	ND - 19.0	-
Clarkson	Lake Trout	17.0 - 57.0	27.4
Credit River	Coho Salmon	ND	-
Humber Bay	Lake Trout	6.0 - 8.0	7.8
	Rainbow Trout	7.0 - 10.0	8.0
Toronto - Hearn GS	Rainbow Smelt	ND - 11.0	-
Scarborough	Lake Trout	ND - 1.0	-
Port Hope	Rainbow Trout	7.0 - 11.0	-
Bay of Quinte	Yellow Perch	ND	-
	White Perch	ND - 16.0	-

TABLE 5: Average Concentrations of Organochlorine Residues in Cows' Milk in Ontario - 1983

Chemical	Average Concentration (ug/kg butterfat)[1]	(ug/kg whole milk)[2]	Estimated Human Exposure[3] (mg/y)
Total DDT	12	0.46	0.011
A-HCH	6.2	0.24	0.006
G-HCH	4.8	0.18	0.004
Heptachlor epoxide	3.4	0.13	0.003
Dieldrin	6.2	0.24	0.006
HCB	0.67	0.02	0.0004
Total PCBs	24	0.91	0.021
PCP	29	1.10	0.026

Note:
A = alpha
G = gamma
[1] = See reference 30
[2] = Calculated by the author assuming a butterfat content of 3.8%.
[3] = Calculated by the authors assuming an estimated annual average consumption of 23.62 litres/y (calculated from reference 21).

TABLE 6: Average 1975 Concentrations and Estimated Exposure to Organochlorines in Canadian Human Whole Milk Samples

Chemical	Average Concentration (ng/g)	Max. Concentration Observed' (ng/g)	Estimated Exposure' (mg/d)	
PCB, as Aroclor 1260	12	68	40.8	0.0408
HCB	2	21	12.6	0.0126
B-HCH	2	21	12.6	0.0126
Heptachlor epoxide	1	3	1.8	0.0018
Oxychlordane	1	2	1.2	0.0012
Trans-Nonachlor	1	2	1.2	0.0012
p,p-DDE	35	144	86.4	0.0864
Dieldrin	2	6	3.6	0.0036
o,p-DDT	3	48	28.8	0.0288
p,p-DDT	6	21	12.6	0.0126

Note:
B = beta
' = See reference 33
' = Calculated by the author assuming an average ingestion of 600 ml of milk a day (see reference 34)

TABLE 7: Mean Concentrations and Estimated Exposure to PCBs in Human Milk Samples from Ontario Residents 1971 - 1985

Year	Concentration		Estimated Exposure[3] (mg/d)
	Mean[1] (mg/kg fat)	Mean[2] (mg/kg whole milk)	
1971-72	1.20	0.036	0.022
1973-74	1.18	0.035	0.021
1977	0.80	0.024	0.014
1978	0.066	0.002	0.001
1979	0.96	0.028	0.017
1981	0.79	0.024	0.014
1983	1.24	0.037	0.022
1985	0.67	0.020	0.012

Note:
[1] = See reference 35
[2] = Calculated by the author assuming an average fat content of 3%
[3] = Calculated by the author assuming an average ingestion of 600 ml of milk a day (see reference 34)

TABLE 8: Summary of Average Concentrations and Estimated Human Exposure to Organochlorines in Beef and Pork Fat from Ontario (1981) and Estimated Human Exposures

Chemical	Beef			Pork		
	Mean Concentration[1] (ug/kg fat)	SD[1]	Estimated Human Exposure[2] (mg/y)	Mean Concentration[1] (ug/kg fat)	SD[1]	Estimated Human Exposure[2] (mg/y)
Total DDT	12	52	0.040	5	7	0.013
Dieldrin	5.7	7.2	0.019	<1	-	-----
Heptachlor epoxide	4.2	8.0	0.014	<1	-	-----
Chlordane	1.1	2.5	0.003	<1	-	-----
A-HCH	6.6	6.7	0.022	1.1	1.8	0.002
G-HCH	2.9	23.6	0.010	13	39	0.032
PCB	9.5	22.5	0.032	3	5	0.008

Note:
A = alpha
G = gamma
[1] = See reference 36
[2] = Calculated by the author, assuming an average fat content of 20% and an estimated average consumption of 16.81 kg/y (calculated from reference 26)
[3] = Calculated by the author, assuming an average fat content of 30% and an estimated average consumption of 7.55 kg/y (calculated from reference 21)

TABLE 9: Summary of Organochlorine Residues in Chicken and Egg Fat (1981 - 1982) and Estimated Human Exposure

	Chicken		Eggs	
Chemical	Mean Concentration[1] (ug/kg fat)	Estimated Human Exposure[2] (ug/y)	Mean Concentration[1] (ug/kg fat)	Estimated Human Exposure[3] (ug/y)
Total DDT	2.3	6.18	3.9	8.95
Dieldrin	0.74	1.99	ND	-----
Heptachlor epoxide	4.6	12.36	ND	-----
Chlordane	4.6	12.36	ND	-----
G-HCH	0.4	1.07	ND	-----
PCB	4.8	12.90	ND	-----

Note:
G = gamma
[1] = See reference 37
[2] = Calculated by the author, assuming an average fat content of 17% and an estimated average consumption of 15.81 kg/y (calculated from reference 21)
[3] = Calculated by the author, assuming an average fat content of 17%, the average weight of an egg to be 75g and an estimated average consumption of 13.50 kg/y (calculated from reference 21)

TABLE 10: Estimated Annual Consumption of Fresh Food by Ontario Residents (1982) and Relative Proportions in Composite Samples

Fresh Meat and Eggs

	Estimated Annual Consumption[1] (kg/person/y)	Composite (%)
Beef muscle	9.70	16.17
Hamburger	7.14	11.90
Pork muscle (incl. cured)	12.10	20.17
Veal	1.02	1.70
Lamb and Mutton	0.76	1.27
Liver	0.65	1.08
Chicken	15.13	25.22
Eggs	13.50	22.50
TOTAL	60.00	100.00

Root Vegetables including Potatoes

	Estimated Annual Consumption[1] (kg/person/y)	Composite (%)
Potatoes	24.12	81.05
Carrots	3.93	13.21
Radishes	0.34	1.14
Turnips/ Rutabegas	0.72	2.42
Others	0.64	2.18
TOTAL	29.75	100.00

Fresh Fruit

	Estimated Annual Consumption[1] (kg/person/y)	Composite (%)
Apples	11.69	68.60
Peaches/ nectarines	2.56	15.02
Pears	1.88	11.03
Plums	0.91	5.34
TOTAL	17.04	100.00

TABLE 11: Concentrations of Selected Persistent Toxic Organochlorines Detected in Food Composites (1985) (ug/g)

Chemical	Minimum Detection Level	Leafy Veg.	Fruit	Root Veg. including Potatoes	Milk	Eggs/Meat
1,3-Dichlorobenzene	0.0001	ND	0.0044	0.0011	0.0014	ND
1,4-Dichlorobenzene	0.0001	ND	ND	ND	0.0055	ND
1,2-Dichlorobenzene	0.0001	ND	ND	ND	ND	0.0018
1,3,5-Trichlorobenzene	0.00001	0.00028	0.00012	ND	0.00012	0.0007
1,2,4-Trichlorobenzene	0.00001	0.0004	0.00014	ND	0.00014	0.00074
1,2,3-Trichlorobenzene	0.00001	0.00011	ND	ND	ND	ND
1,2,3,5/1,2,4,5-Tetrachlorobenzene	0.00001	ND	ND	ND	ND	ND
1,2,3,4-Tetrachlorobenzene	0.00001	ND	ND	ND	ND	ND
Pentachlorobenzene	0.00001	ND	ND	ND	ND	ND
Hexachlorobenzene	0.00001	0.00002	ND	0.00004	0.00016	0.00017
A-HCH	0.00001	ND	0.00002	ND	0.00013	0.00013
G-HCH	0.00001	0.00007	0.0001	0.00005	ND	0.0021
Heptachlor	0.00001	ND	ND	ND	ND	ND
Aldrin	0.00001	ND	ND	ND	ND	ND
Oxychlordane	0.00001	0.00004	ND	ND	0.00008	0.00013
Heptachlor Epoxide	0.00001	ND	ND	ND	0.00021	0.00012
A-Chlordane	0.00001	ND	0.00013	0.0001	0.0001	0.00012
G-Chlordane	0.00001	0.00006	0.00006	0.00004	0.00002	ND
A-Endosulfan	0.00001	0.0038	0.0014	ND	ND	ND
p,p'-DDE	0.00001	0.0002	0.0046	0.00039	0.00027	0.0031
Dieldrin	0.00001	0.0031	0.00011	0.023	0.0019	0.0031
Endrin	0.00001	0.00032	0.00027	0.00037	0.00027	ND
b-Endosulfan	0.00001	0.017	0.0057	0.00071	0.0022	ND
p,p'-DDD	0.00001	0.00034	ND	0.00047	ND	0.00017
o,p'-DDT	0.00001	0.00002	ND	ND	ND	ND
p,p'-DDT	0.00001	0.00042	0.00039	0.065	0.0014	0.00031
Photomirex	0.00001	ND	ND	ND	ND	ND
Mirex	0.00001	ND	ND	ND	ND	ND
Methoxychlor	0.0001	ND	ND	ND	ND	ND
Total PCB	0.0001	ND	0.0007	ND	0.0001	0.0003

Note:
ND = Not detected
A = alpha
B = beta
G = gamma

TABLE 12: Concentrations of PCDDs and PCDFs in Food Composites (1985) (ug/g)

Congener Group	Minimum Detection Limit	Root Veg including Potatoes	Fruit	Leafy Veg.	Milk	Meat/Eggs
T4CDF	0.0000001	ND	0.000045	ND	0.00012	0.00005
T4CDD	0.0000001	ND	ND	0.0000004	0.0000025	ND
P5CDF	0.000001	ND	0.00028	ND	0.0000076	0.000016
P5CDD	0.000001	ND	0.000005	ND	ND	ND
H6CDF	0.000001	0.000002	0.002	ND	ND	ND@0.005
H6CDD	0.000001	ND	0.00045	ND	ND	ND
H7CDF	0.000001	0.000039	0.0066	ND	0.000013	ND
H7CDD	0.000001	0.000012	0.0012	ND	0.0000034	ND
O8CDF	0.000001	0.00013	0.0012	ND	0.000058	0.0000018
O8CDD	0.000001	0.00001	0.00012	ND	0.000036	ND

Note:
ND = Not detected
N/A = Not appropriate

TABLE 13: Estimated Annual Dietary Intake of Selected Persistent Toxic Organochlorines from Fresh Food Composites (1985)

Chemical	Intake										
	Fruit		Leaf Veg.		Root Veg. including potatoes		Milk		Eggs/Meat		Total Estimated Annual Intake (ug/y)
	Estimated Intake (ug/y)	% of Total	Estimated Intake (ug/y)	% of Total	Estimated Intake (ug/y)	% of Total	Estimated Intake (ug/y)	% of Total	Estimated Intake (ug/y)	% of Total	
Total PCBs	11.9	32.6	---	0	---	0	6.62	18.1	18.0	49.3	36.5
a-HCH	0.3	1.8	---	0	---	0	8.6	51.5	7.8	46.7	16.7
g-HCH	1.7	1.3	2.14	1.6	1.5	1.1	---	0	126.0	95.9	131.3
Heptachlor epoxide	---	0	---	0	---	0	13.9	65.8	7.2	34.1	21.1
Dieldrin	1.9	0.2	94.9	8.7	684.5	62.6	125.8	11.5	186.0	17.0	1093.1
a-Chlordane	2.2	11.6	---	0	3.0	15.8	6.6	34.7	7.2	37.9	19.0
g-Chlordane	1.0	18.7	1.83	34.3	1.2	22.5	1.3	24.4	---	0	5.33
Oxychlordane	---	0	1.22	8.5	---	0	5.3	37.0	7.8	54.5	14.32
a-Endosulfan	23.9	17.0	116.28	83.0	---	0	---	0	---	0	140.1
b-Endosulfan	97.1	12.4	520.2	66.3	21.1	2.7	145.6	18.6	---	0	784.0
Endrin	4.6	10.6	9.79	22.6	11.0	25.4	17.9	41.4	---	0	43.3
o,p'-DDT	---	0	0.61	100	---	0	---	0	---	0	0.61
p,p'-DDT	6.6	0.3	12.9	0.6	1934.4	93.6	92.7	4.5	18.6	0.9	2065.2
p,p'-DDE	78.4	26.1	6.1	2.0	11.6	3.8	17.9	6.0	186.0	62.0	300.0
p,p'-DDD	---	0	10.4	30.0	14.0	40.5	---	0	10.2	29.5	34.6
1,3-Dichlorobenzene	75.0	37.4	---	0	32.7	16.3	92.7	46.3	---	0	200.4
1,4-Dichlorobenzene	---	0	---	0	---	0	364.1	100	---	0	364.1
1,2-Dichlorobenzene	---	0	---	0	---	0	---	0	108.0	100	108.0
1,3,5-Trichlorobenzene	2.0	1.6	8.57	6.5	---	0	79.4	60.2	42.0	31.8	132.0
1,2,4-Trichlorobenzene	2.4	3.8	12.2	18.0	---	0	9.3	13.6	44.4	64.9	68.4
1,2,3-Trichlorobenzene	---	0	3.36	100	---	0	---	0	---	0	3.36
Hexachlorobenzene	---	0	0.61	2.7	1.2	5.3	10.6	46.9	10.2	45.1	22.6
Average % by composite		7.9		22.0		17.7		21.8		30.4	

Note:
Data were calculated from Tables 10 and 11
A = alpha
B = beta
G = gamma
--- = No intake

TABLE 14: Estimated Dietary Intake of PCDDs and PCDFs from Fresh Food Composites (1985)

Intake ug/y

Chemical	Fruit		Leaf Veg.		Root Veg. including potatoes		Milk		Eggs/Meat		Total Estimated Annual Intake (ug/y)
	Estimated Intake (ug/y)	% of Total	Estimated Intake (ug/y)	% of Total	Estimated Intake (ug/y)	% of Total	Estimated Intake (ug/y)	% of Total	Estimated Intake (ug/y)	% of Total	
T4CDF	0.77	6.5	---	0	---	0	7.94	67.8	3.00	25.6	11.71
T4CDD	---	0	0.01	5.8	---	0	0.16	94.1	---	0	0.17
P5CDF	4.77	76.6	---	0	---	0	0.50	8.0	0.96	15.4	6.23
P5CDD	0.08	100	---	0	---	0	---	0	---	0	0.08
H6CDF	34.08	99.8	---	0	0.06	0.2	---	0	---	0	34.14
H6CDD	7.67	100	---	0	---	0	---	0	---	0	7.67
H7CDF	112.46	98.2	---	0	1.16	1.0	0.86	0.8	---	0	114.48
H7CDD	20.45	97.2	---	0	0.36	1.7	0.22	1.0	---	0	21.03
O8CDF	20.45	72.3	---	0	3.9	13.7	3.84	13.6	0.11	0.4	28.3
O8CDD	2.04	43.2	---	0	0.3	6.4	2.38	50.4	---	0	4.72
Average % by composite		69.4		0.5		2.3		23.6		4.1	

Note:
Data were calculated from Tables 10 and 12
--- = No intake

TABLE 15: Exposure Assessment for a Representative Ontario Adult

Food	Chemical							Av. % by food type	Av. % by Exposure Route
	PCB	Total DDT	Aldrin/ Dieldrin	Heptachlor	HCB	A,B-HCH	G-HCH		
Fish[1]									
mg/y	0.209	0.052	ND	ND	0.002	0.015	0.001		
% food exposure	70.8	6.2	0	0	66.6	33.3	2.0	25.6	----
Cows' milk[2]									
mg/y	0.021	0.011	0.006	0.003	0.0004	0.006	0.004		
% food exposure	7.1	1.3	2.1	10.3	13.3	13.3	8.0	7.9	----
Beef/Pork[3]									
mg/y	0.04	0.053	0.019	0.014	----	0.024	0.042		
% food exposure	13.5	6.4	6.6	48.2	----	53.3	84.0	30.3	----
Chicken/Eggs[4]									
mg/y	0.013	0.015	----	0.012	----	----	0.001		
% food exposure	4.4	1.8	----	41.3	----	----	2.0	7.1	----
Fruit/Veg.[5]									
mg/y	0.012	0.700	0.260	ND	0.0006	0.0001	0.0018		
% food exposure	4.1	84.2	91.2	0	20.0	0.2	3.6	29.0	----
TOTAL FOOD									
mg/y	0.295	0.831	0.285	0.029	0.003	0.0451	0.050		
% total exposure	98.6	99.9	99.2	100	56.6	63.4	82.2	----	85.7
DRINKING WATER[6]									
mg/y	ND	0.0002	0.002	ND	0.0015	0.025	0.003		
% total exposure	0	0.02	0.7	0	28.3	35.2	4.9	----	9.8
AIR[7]									
mg/y	0.0039	0.0001	0.0002	----	0.0008	0.001	0.0078		
% total exposure	1.3	0.01	0.07	----	15.1	1.4	12.8	----	4.4
TOTAL EXPOSURE									
mg/y	0.2989	0.8313	0.2872	0.029[8]	0.0053	0.0711	0.0608		

Note:
A = alpha
G = gamma
[1] = See Table 3 for rainbow trout
[2] = See Table 5
[3] = See Table 8 (estimated exposures for pork and beef were averaged)
[4] = See Table 9 (estimated exposures for chicken and eggs were averaged)
[5] = See Table 13 (estimated exposures for fruit, leafy vegetables and root vegetables were averaged)
[6] = See Table 2
[7] = Because there are no data on ambient concentrations of these chemicals in Ontario's air; it was necessary to assume the data shown in Table 1
ND = Not detected
---- = Information not available

TABLE 16: Exposure Assessment for a Representative Toronto Adult

Estimated Average Human Exposure

Chemical	Fresh Food[1] (mg/y)	%	Drinking Water[2] (mg/y)	%	Air[3] (mg/y)	%	Total (mg/y)
A-HCH	0.017	39.5	0.025	58.1	0.001	2.3	0.043
G-HCH	0.131	94.2	0.0003	0.2	0.0078	5.6	0.1391
Aldrin/Dieldrin	1.093	99.7	0.002	0.2	0 0002	Neg.	1.0952
Total DDT	2.400	99.9	0.0002	Neg.	0.0001	Neg.	2.4003
HCB	0.0226	90.7	0.0015	6.0	0.0008	3.2	0.0249
PCB	0.0365	90.3	ND	----	0.0039	9.6	0.0404
Average % by all exposure route		85.7		10.8		3.5	

Note:
A = alpha
G = gamma
[1] = See Table 13
[2] = See Table 2
[3] = Because there are no data on ambient concentrations of these chemicals in Toronto's air, it was necessary to assume the data shown in Table 1.

Leafy and Other Above Ground Vegetables

	Estimated Annual Consumption[1] (kg/person/y)	Composite (%)
Green/Wax beans	0.66	2.16
Broccoli	1.12	3.66
Cabbage	1.77	5.78
Cauliflower	1.88	6.14
Celery	1.76	5.75
Corn	0.74	2.42
Cucumber	2.58	8.43
Lettuce	6.63	21.67
Mushroom	0.74	2.42
Onion	3.99	13.04
Pepper	1.08	3.53
Tomato	5.52	18.04
Other seed/gourd[3]	1.16	3.79
Other leaf/stalk[4]	0.97	3.17
TOTAL	30.60	100.00

Cow's Milk

	Estimated Annual Consumption[1] (litres/person/y)	Composite (%)
2% Milk	66.2	100

Note:
[1] = See Table 3
[2] = Other root vegetables were beets
[3] = Other seed/gourd were zucchini, squash and vegetable marrow.
[4] = Other leaf/stalk were green onion stalks.